UNIVERSITY OF
THE UNIVERSITY
12 FEB 1963
USAF ACADEMY

OAR
RESEARCH REVIEW
OFFICE of AEROSPACE RESEARCH

OAR:
The Basic Research Agency
of The United States Air Force

A F OFFICE OF SCIENTIFIC RESEARCH / A F CAMBRIDGE RESEARCH LABORATORIES / AERONAUTICAL RESEARCH LABORATORIES / EUROPEAN OFFICE. O A R

VOLUME II NUMBER 1 11 FEBRUARY 1963

Similitude Considerations in Space-Environmental Simulation

Dr. TAU-YI TOONG, Consultant, Office of Research Analysis

I. Introduction

Simulation of space environment has become a problem of great interest during recent years. As man's increasing space activities become more varied and complex, it becomes both desirable and necessary to provide means of laboratory testing under simulated conditions.

Environmental conditions which are known to be of varying degrees of importance in different problems are listed below:

(1) Low pressure, density and temperature
(2) Solar radiation
(3) Albedo and planet radiation
(4) Cosmic and nuclear radiation
(5) Atmospheric composition and energy state of gases
(6) Electromagnetic fields
(7) Force fields, including gravitational, acceleration and vibration
(8) Meteor impact

The laboratory simulation of the first three items seems quite feasible at present, while that of the remaining items either is beyond present technology or can be achieved only by the use of special equipment. As these conditions may strongly interact in a very complex manner in a given problem, a really useful space-simulation chamber would be one in which

all the relevant environmental conditions have been properly simulated.

The problem of simulation becomes even more difficult when one is thinking of simulation as being reproduction (to various degrees of fidelity) of a certain effect in its absolute magnitude. Indeed, in some cases, correct simulation can be achieved only through reproduction of an appropriate effect in its absolute magnitude. However, in many other cases, this is not necessary. The use of similitude rules or model testing (e.g., in wind tunnels) has demonstrated very vividly that much knowledge can be obtained by simulating only the relative effects of relevant quantities.

This note is intended to briefly describe some of these similitude considerations in space applications. An example is given to indicate how subgravitational effects can be studied in an earth-bound laboratory. Conjectures are also made as to possible effects of subgravity on human locomotion and heart beat. It appears that much understanding of the subgravitational effects on man can also be achieved by the use of the similitude rules.

II. Similitude Considerations

Let us take as an example a fluid-flow problem in which it is desired to predict the effect of a subgravitational field. As is well known, it is very difficult, if not impossible, to truly simulate subgravity for long duration in earth-bound laboratories. However, if one uses the similitude rules, one can predict the behavior of a system under such conditions.

First, let us assume that the relevant forces to be considered in this example are those due to pressure, gravity, inertia, viscosity and surface tension. Four independent dimensionless parameters can thus be formed from the ratio of any two of the five forces; for example, pressure-drag coefficient (pressure-drag/inertia), Froude number (inertia/gravity), Reynolds number (inertia/viscous) and Bond number (gravity/surface tension). Let us further assume that, for normal values of gravity and surface tension, the Bond number is rather unimportant. One obtains, then, from dimensional analysis:

Drag coefficient = f (Froude number, Reynolds number)

or

$$D/\rho v^2 \ell^2 = f(v^2/\ell g,\ v\ell/\nu)$$

where $D, \rho, \nu, v,$ and g are the pressure-drag, characteristic fluid density and kinematic viscosity, characteristic velocity, characteristic length and gravity, respectively. This relationship should hold, within its region of validity, regardless of the values of the velocity, length, kinematic viscosity, density and (indeed also) gravity.

It should be pointed out, however, that the Bond number (as well as the Froude number) assumes different values as the gravity changes and may become an important parameter. In particular, under subgravity, the surface tension may become comparable to the gravitational force and thus assumes an important role. In other words,

$$D/\rho v^2 \ell^2 = f(v^2/\ell g,\ v\ell/\nu,\ \rho g \ell^2/\sigma)$$

where σ is the surface tension. This expression indicates that one can study the subgravitational effect in this problem in an earthbound laboratory by choosing a small length (ℓ) or a

large kinematic surface tension (σ/ρ) so that the Bond number would assume a value of the same order of magnitude under normal and subgravity conditions.

III. Effects of Subgravity on Man

Questions have been raised as to possible effects of subgravity on human beings. Two major difficulties present themselves in a study of such effects in earth-bound laboratories; first, it is difficult to simulate subgravity on earth for long durations and, secondly, it is impossible to scale human beings up or down. However, some conceivable conjectures can be made as to some of these effects.

To be specific, let us ask ourselves what would happen to man's mobility and heart beat should he live on the moon where the gravitational field is only about one-sixth of the earth's field. In this connection, we expect that the following two natural frequencies are relevant: one depending on a gravitational spring and the other on a muscular spring. The former natural frequency would be smaller on the moon and the latter, presumably, would remain the same, should his muscles retain their strength. It seems reasonable to expect that the man's mobility depends very much on his natural frequency. His mobility in that type of motion which depends on the gravitational spring would be greatly impaired, just like the mobility of a "giant" (six times taller or two hundred sixteen times heavier than a normal man) would be impaired on the earth. Furthermore, the frictional force expected to be available on the lunar surface for self-propulsion would be less. Thus, man's locomotion on the moon could indeed become very difficult.

Because of lack of exercise,* the man's muscles would become weaker. Thus, the natural frequency dependent thereon would also decrease and this would further affect his ability in locomotion.

It was pointed out to the author by Dr. Harald J. von Beckh** that part of the effort of a human heart is spent to overcome gravity. It would seem that a lighter load is imposed on the heart of a man on the moon and thus his heart beat slows down. Because of the weakening muscle and decrease in natural frequency, the human heart might possibly degenerate to such an extent that its beat slows down further to something corresponding to the "normal heart beat of an abnormal giant" on the earth. The situation might become even worse should he again return to the earth's gravitational field with his weakened heart.

The above conjectures seem to indicate that man might not be of the optimum size and build for a long-term stay on the moon. It would be of great interest to be able to verify or disprove these conclusions in an earth-bound laboratory, where simulation of subgravity effect can be performed along the arguments presented above for the fluid-flow problem without reproducing the absolute value of the gravity. This would become possible if some basic understanding of the fundamental processes of man's locomotion and heart beat (and other activities) can be achieved on the earth.

---

*It is suggested that a man should probably keep himself physically fit on the moon by carrying with him a gravity-simulation machine, e.g., a centrifuge.

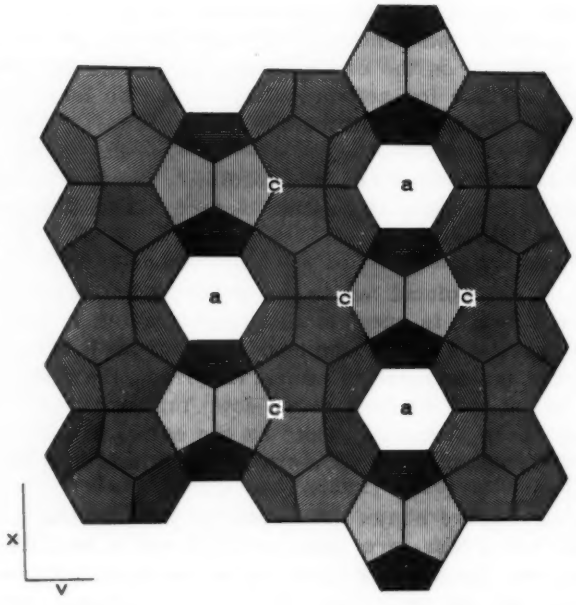
**Technical Director, 6571st Aeromedical Research Laboratory, Holloman Air Force Base, New Mexico.

a mixture of WATER and GREECE

DENTON W. ELLIOTT, Directorate of Chemical Sciences (AFOSR)

The citizens of the ancient Greek city of Syracuse were well aware of the importance of basic research to the welfare of the state; especially after they saw the devices of the scientist Archimedes destroy the famed military power of the Romans. The residents of the modern city of Syracuse, New York, and all Americans, are also protected by the military use of science, including some of the science developed by the predecessors of Archimedes.

Archimedes was aware that there are only four strictly regular polyhedra, the tetrahedron, cube octahedron and icosahedron. All other polyhedra, such as the twelve sided dodecahedron, are not strictly regular. At a recent international conference held appropriately enough at Athens, Greece, Professor G. A. Jeffrey of the University of Pittsburgh reported on the importance of this ancient observation to a perennial problem of great military and civilian importance: an adequate supply of drinkable water.



Water forms a very interesting series of molecular compounds called clathrate hydrates, in which a cage structure made of water molecules is found to trap or enclose a different species of molecule. The association between host and guest molecules does not require primary chemical binding, so that the two types can be separated at little cost in energy. In research supported by AFOSR, Dr. Jeffrey

has made detailed studies of the structure of these substances.

Dozens of clathrate hydrates are known. Some involve the inert gases, such as 6 Ar · $46H_20$; other examples are 8 C_3H_8 · 136 H_20 and 6 C_12 · $46H_20$. Such compounds are generally crystalline, can be easily recrystallized, and have possible application in purification processes. In fact, the propane hydrate is the basis of a water desalination procedure. An interesting suggestion has been made that the gas hydrates may be found elsewhere in the solar system, even through they have not been found to occur naturally on our own planet.

X-ray studies by Dr. Jeffrey confirmed earlier suggestions that the structure is based on a framework of pentagonal dodecahedra, each of which is a hydrogen-bonded aggregate of twenty water molecules, H_{40} 0_{20}. The stability of the clathrates is due to the fact, known to the ancients, that these dodecahedra cannot be close packed to fill space tightly, as would be possible with cubes. Figure 1. shows the gaps that occur when the dodecahedra are put together to form a regular crystal lattice; these are the places in which the guest molecules are trapped.

Of what importance is this to the citizens of Syracuse? Many of the clathrates studied have potential use for obtaining pure water from contaminated sources. This would have been valuable to the ancient argonauts, and may be come highly useful to future Astronauts.

AFCRL notes

In the October issue of the AFCRL Research Bulletin, announcement was made of a gallium arsenide laser, developed by GE, that produces continuous output when energized by ordinary current. A second major advance under an AFCRL contract has now been announced. Using gallium arsenide-phosphide junctions, GE has achieved coherent visible light radiations at room temperature and is able to control the wavelength of these radiations by simply changing the chemical composition of the crystal. The p-n junction laser can be built with an output wavelength which can be selected in the range from about 6200A to near 8400A. (Electronic Material Sciences Laboratory)

PLANET FORMATION and COMPOSITION

DWIGHT L. WENNERSTEN, General Physics Div. (AFOSR)

Aside from the importance of the question, "From whence cometh ....."? to philosophical science, there is another science concerned with the same question. This is cosmogony, the study of the origin and evolution of the solar system. For the "eager" and the unwary, it is an exasperating sub-branch of astrophysics because of the myriad of phenomena that contribute to it and the regularity with which seemingly brilliant hypotheses are upset by others. Yet its facination is irresistible and most physical scientists are drawn into some phase of its activities at one time or another.

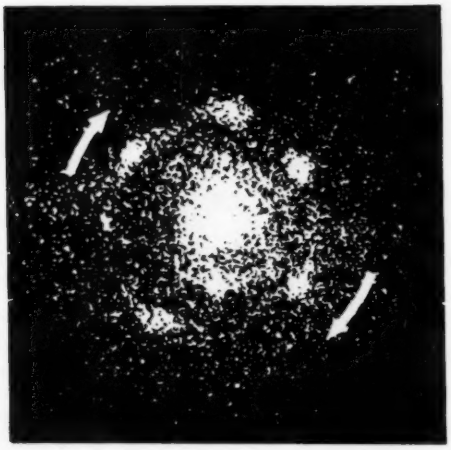
The phenomena to be reconciled are deceptively simple. Any cosmogonical theory must be compatible with three principal factors: the age of the earth, the distribution of angular momentum in the solar system, and the chemical composition of the planets and the sun. Even the secondary factors to be accounted for are not too dismaying... in recital at least. These include: regularities in the motions of the planets, their distances from the sun[1], and their direct and retrograde (backwards) motions around the sun; planetary satellites and their direct and retrograde motions; Saturn's rings, minor planets (asteroids); cometary-associated meteor showers; and finally, the 50-50 balance between star masses and the combination of gas and dust in our portion of the galaxy where the sun is situated.

Going back to the primary factors: chronological age, angular momentum, and chemical composition; there is practically universal agreement among cosmogonists that:

(1) Planets, satellites, and comets were all formed as condensations in the original "solar nebula" where 99.9% of the mass went into the central body, the sun, and that (2) the solar system is about, or at least, 5×10^9 (billion) years old.

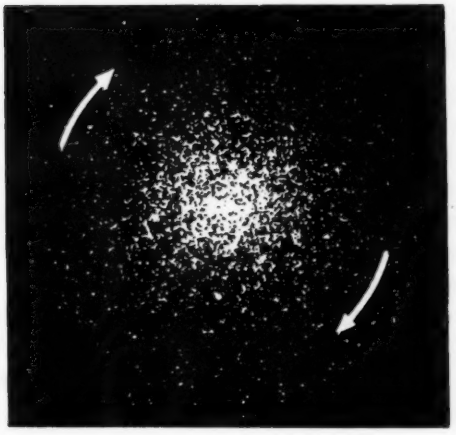
From these points of present agreement, departures among astronomers and astrophysicists seem almost random, and it has been so since the start of "quantitative" astronomy 200 years ago when Herschel improved the quality of telescopic mirrors to a point where magnifications in excess of 6000 became possible, and careful observations led him to theories concerning star associations and nebulae.

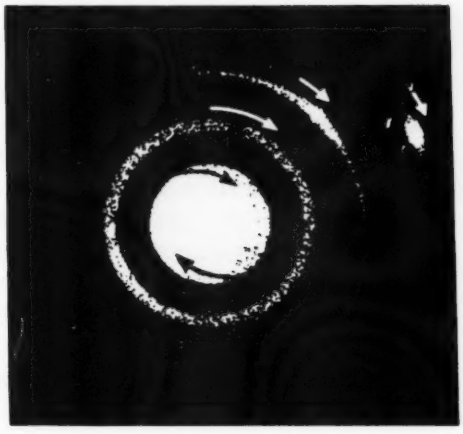
The first of the three modern hypotheses of solar system cosmogony was Kant's Theory (1755), describing a rotating nucleus of gas and dust wherein the central condensation containing the bulk of the mass formed, gradually, the sun, with subsidary whorls at a distance from the large center forming the planets. The planetary whorls were important because they "took up" the excess angular momentum of the gross system as it contracted. Later contractions and dust accretion were visualized as



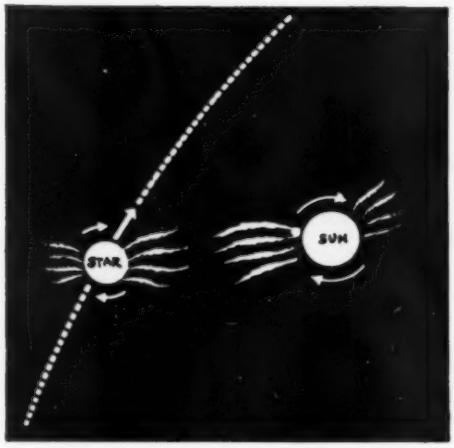
creating "second" instabilities which resulted in moon formations around the various planets again to balance the system dynamically. The weakness of this hypothesis was in the fact that the planets with .0014 of the total mass have 98% of the angular momentum with 2/3 of this 98% identified with a single planet, Jupiter.

A similar scheme, derived by Laplace in 1796, postulated a globular gas mass contracting into a central mass with several rings, a la Saturn, these rings then condensing into the planets.





The third hypothesis grew out of a series of challenges to the models listed above over the next century. This was the Chamberlin-Moulton Theory which proposed the "near-miss" hypothesis, wherein a wandering star was supposed to have passed close to the sun, pulling matter toward the "passer", and vice versa. The intruder then rushed away leaving the extracted matter from the sun in a single plane to gather into ten planets by a not-yet-identified spacing law (See Note 1).



This theory also has been challenged, notably by Alfven in recent years. Alfven points out, quite logically, that the sun has a magnetic field, and that the sun could have expended an enormous quantity of rotational energy by magnetic braking, or magnetic hydrodynamic transfer, in the last five billion years since the earth (and probably the other planets) were formed. Thus the Laplace theory might again be credible on this basis. For instance, the sun ejects four million tons of radiation and ionized-particle mass per second. These latter are reluctant to cross magnetic lines, so will carry enormous rotational energies with them in leaving the sun along guided magnetic ducts.

There have been other hypotheses advanced as understanding of non-linear mechanics and turbulence theory increased. For instance, von Weizsacker presented a revised Kant hypothesis in 1945. This model starts with a nebulous center of 0.1 solar mass of gas which is accompanied by a group of detached smaller turbulent vortices. Von Weizsacker then shows that once formed, variational statistical mechanics predicts that this system follows a time history consistent with our solar system and accounts for the planetary masses and their distribution or dispersion over the range of 7^{o} around a median planetary plane (the ecliptic). This hypothesis calls for gradual accretion of the final 90% of the mass of the system from galactic hydrogen and dust.

The contemporary astronomer Kuiper has presented a development calling for the sun to have a smaller companion quite close to it. Under a fairly high angular momentum condition, the smaller companion is shown to follow a history consistent with flattening into an ellipsoid and then rupturing into the smaller planet distribution characteristic of our solar system. This hypothesis is attractive because of the great number of unequal-mass binary star systems which have been observed spectroscopically or by the periodic eclipsing of one by the other.

Of late, researches supported by AFOSR have contributed some clarification to the theories including also the nucleogenic processes which describe the known element abundances of the inner (terrestrial) and the outer (Jovian) planetary groups. For instance, Dr. A. G. N. Cameron[2], with the Cal Tech-Mt. Palomar group has analyzed the nuclear decay time scales for elements trapped in iron and stony meteorites to set the early history of the sun and condensing planets of our solar system. He used the radioactive species aluminum-26, palladium-107, and iodine-129 to set the time scales of 6×10^6 years for condensation of silicates (stones), 3×10^7 years for iron solidification, and 1.5×10^8 years for the end of gravitational collapse of the sun to a main sequence or "quiet" star. A second AFOSR-supported group at the Cal Tech-Palomar complex reports[3] in a related study that the sun-planet system conditions whereby the proto-sun expells at least two sets of planetary nebular rings in concert with great magnetic activity can be observed today in two classes of variable "new" stars, one called T Tauri stars and the other "magnetic type A" stars. Both are found in the gas and dust-rich protions of the arms of our galaxy and nearby galaxies. These stars are characterized by high magnetic fields (up to 34,000 gauss) or extreme variability in luminosity and super abundances of the light metal isotopes lithium-6 and boron-10. A third study was reported in the AFOSR-Cloudcroft Seminar on Astrophysics in June 1962 by Professor H. C. Urey of the University of California, LaJolla.[4] He reviewed the present knowledge of the time-and-temperature histories of the moon, the sun, meteorites and, to the extent known, of the other planets. He reached a nearly identical time scale, to that reported above. One new description is contained in Professor Urey's work. His model provides for the Jovian planet group to separate at an early stage of contraction of the proto-sun followed perhaps another 10^6 years later by the separation of a second nebular ring to make the terrestrial planet group with their greater abundance of heavier elements. This refinement is a considerable departure from earlier "mechanistic" models.

So cosmogony progresses -- but is not yet complete. New observational data are expected to accelerate progress in cosmogony.

1 Bode's Rule: $D = 0.4 + (0.3 \times 2^m)$. In this equation m varies from -1 for mercury, 0 for venus, +1 for earth to +8 for Pluto. D is measured in astronomical units equal to the average earth's distance from the sun, 92 million miles.

2 "The Formation of The Sun and Planets"; ICARUS 1, 13 (1962).

3 "Nucleosynthesis during the early history of the Solar System"; W. Fowler, J. Greenstein and F. Hoyle; Geo. Phy. J. of the Roy. Astr. Soc.; 6, 148 (1962).

4 "The origin and Evolution of the Solar System", H. Urey, AFMDC Lecture Note Preprint, June 18-19, 1962.

LUNAR ENVIRONMENT SIMULATION

RESEARCH INSTRUMENTATION LABORATORY (AFCRL)

A lunar environment chamber, designed to simulate pressures, temperatures, and solar radiation on the moon has been placed in operation at AFCRL. The research program centered around the chamber is under the direction of Dr. John Salisbury.

The cylindrical chamber itself has a length of 24 inches and a diameter of 14 inches. Temperatures within the chamber can range from minus 150 to plus 134 degrees C. The near-vacuum conditions on the moon are simulated by the chamber's vacuum system which can achieve pressures of less than 2×10^{-10} mm Hg. Ultraviolet, X-ray, and alpha particle radiation can be introduced through three ports in the chamber. These temperatures and pressures closely duplicate those believed to exist on the moon. The radiation used is in excess of solar radiation in order to accelerate the radiation damage phenomena expected.

A number of materials of the type expected on the surface of the moon will be placed in the chamber for study. AFCRL hopes to learn

something of the properties of these materials under lunar conditions. Most important are their emission and absorption spectra, their thermal conductivity, and their mechanical properties.

Presently under investigation are chondrites -- or stormy meteorites. Subsequent studies will be made of tektites, basalt, granodiorite, dunite and serpentine. Prior to introduction into the chamber, these materials are crushed into very fine power, individual particles of which will measure about 10 microns.

The chamber was built for AFCRL by the Ilikon Corporation. Scientists from the A. D. Little Company will participate in the use of the AFCRL chamber, as a part of the overall research program designed by Dr. Salisbury.

estimation of parameters of statistical populations

Dr. H. LEON HARTER, Applied Mathematics Research Laboratory (ARL)

Every statistical population is characterized by one or more parameters. The familiar normal population has two parameters, the mean and the standard deviation, while the one-parameter negative exponential population has, as the name implies, just one parameter, which is both the mean and the standard deviation. A very important problem in mathematical statistics is the estimation of the parameters of these and other populations from sample statistics. A mathematical expression which estimates a population parameter as a function of a sample statistic is called an estimator, while a numerical value obtained from an estimator by substituting a numerical value for the sample statistic is called an estimate.

Distinction should be made at the outset between point estimation and interval estimation. In the former the result is a single value, while in the latter it is an interval with which is associated a specified level of confidence that the population parameter lies in this interval. A point estimator should be unbiased; that is, its expected value should be equal to the value of the parameter. A sample statistic may or may not be an

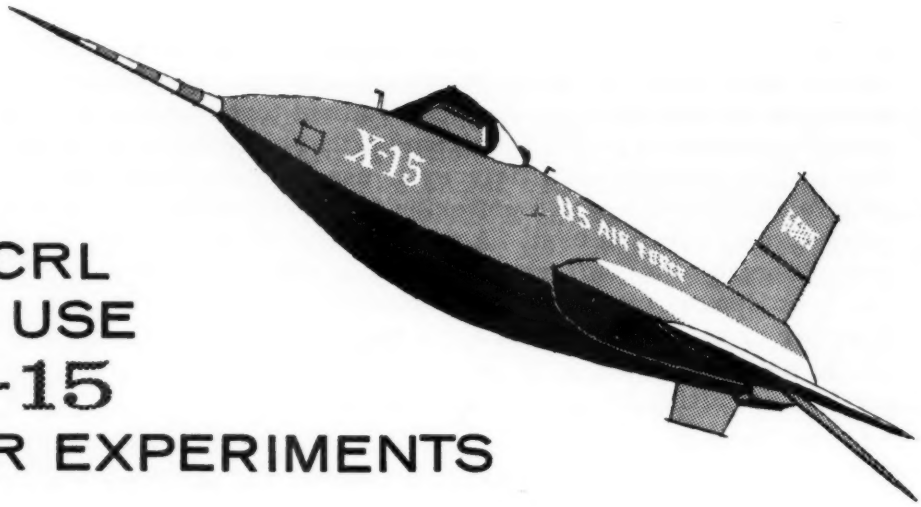
unbiased estimator of the corresponding population parameter. The sample mean is quite generally an unbiased estimator of the population mean, but the sample standard deviation is often (as, for example, in the case of the normal population) a biased estimator of the population standard deviation. If the expected value of the sample statistic is known, but differs from the population parameter, this poses no serious problem; it is a simple matter to multiply the sample statistic by a bias-correcting factor (the ratio of the parameter value to the expected value of the statistic) in order to obtain an unbiased estimator. Of course, a statistic other than the one corresponding to the parameter being estimated may be used; to estimate the population mean, for example, the sample median or some other measure of central tendency in the sample may be used instead of the sample mean. It is also desirable that a point estimator, besides being unbiased, should be efficient; that is, that its variance should be smaller than that of any other unbiased estimator. A great deal of effort has been expended by mathematical statisticians in obtaining minimum variance unbiased estimators for the parameters of various populations. These estimators are so widely used that they are sometimes spoken of as conventional estimators. There are, however, situations in which it may be advantageous to use substitute estimators, which are inefficient, instead of the conventional estimators. These situations may occur when the substitute estimates are much easier to compute or when they can be determined from incomplete data without waiting for all the data necessary to compute the conventional estimates to become available, and when the resulting loss of efficiency is not too great. The efficiency of a substitute estimator is defined as the ratio, expressed as a percentage, of the variance of the conventional estimator to that of the substitute estimator.

An upper (lower) confidence bound for a parameter is a value with which is associated a specified level of confidence that the parameter is less (greater) that the bound. Confidence intervals may be either central or non-central. Let $c \geq -\infty$ and $d \leq +\infty$ be respectively the smallest and largest values which the parameter can possibly assume. Then the interval from c to an upper confidence bound and the interval from a lower confidence bound to d are examples of non-central confidence intervals. The interval from a lower confidence bound to an upper confidence bound, both with confidence $1-\alpha$, is a central confidence interval with confidence $1-2\alpha$. Confidence bounds and confidence intervals may be either exact or approximate, depending upon whether the level of confidence is exactly as specified or only approximately so. Certainly exact bounds or intervals are to be preferred,

but sometimes approximate ones, usually chosen so that the level of confidence is at least the specified value, are used when exact ones are much more difficult to obtain. The requirement that interval estimators be exact is analogous to the requirement that point estimators be unbiased. Just as the criterion of efficiency is used to determine which unbiased point estimator is best, a criterion is needed to determine which exact interval estimator is best. A criterion based on minimizing the expected length of a confidence interval has been extensively used, but it has been demonstrated that this criterion is not entirely satisfactory. A better criterion is one based on maximizing the efficiency of the interval estimator, which is defined by a logical extension of the corresponding definition for a point estimator.

Order statistics are often used as the basis for substitute estimators. The m^{th} order statistic, x_m, of a sample size n is defined as the m^{th} smallest value in the sample. The range, w (or w_0), of a sample of size n is defined as the difference, $x_n - x_1$, between the largest and smallest values. The r^{th} quasi-range, w_r, of a sample of size n is defined as the range, $x_{n-r} - x_{r+1}$, of the $(n-2r)$ sample values which remain after the r largest and the r smallest have been discarded. Note that according to these definitions the range is the 0^{th} quasi-range. A suitably chosen quasi-range will yield quite good estimators for the standard deviation of a symmetric population, but not for an asymmetric one; for the one-parameter negative exponential population, for example, a single order statistic will do better.

The author has computed extensive tables of point and interval estimators, based on order statistics, for the standard deviations of normal, rectangular, and negative exponential populations. These tables and the accompanying theory have been published in several ARL reports and journal articles. In the case of the rectangular population, the estimators based on the sample range are actually the efficient (conventional) ones. For the normal population, the substitute estimators based on sample quasi-ranges are simpler to compute than the conventional ones based on the sample standard deviation. For the one-parameter negative exponential population, the conventional estimators based on the sample mean are quite simple to compute, but substitute estimators based on order statistics may be preferable in some situations, such as life testing, because the sample values become available in an ordered fashion, so that the necessary data becomes available sooner for the substitute estimates than for the conventional ones.



AFCRL TO USE X-15 FOR EXPERIMENTS

Three AFCRL instrument packages will be installed in the X-15-3 for measuring atmospheric densities and characteristics of the engine plume, and for the collection of micrometeorites at extreme altitudes.

To measure the infrared signature of the ammonia-lox engine exhaust, a 15-pound package will be installed either on the upper stabilizer or the side fairing blow-out panel. The IR radiometer is designed to measure radiation in four spectral regions by focusing radiation through four selective filters on a lead sulfide detector. The IR range is from 0.5 to 2.8 microns. Three to five flights are planned. In some flights the instrument will face the exhaust; in others the instrument will face 90 degrees from the exhaust.

For measuring atmospheric density, a radioactive ionization gauge exposed to ram air will be used. The three and one-quarter pound gauge will probably be mounted on a wing-tip pod. Variations in atmospheric densities at a given altitude level above 100,000 feet are of particular interest. Extreme care must be taken to provide adequate heat protection to the gauge.

The micrometeorite collection experiment is designed for flights exceeding 150,000 feet. A ram air scoop encasing a millipore filter will be used, and it is proposed that the apparatus have the capability of discriminating between high and low velocity particles. Care must be taken to prevent contamination by terrestrial particles and by aircarft exhaust products. The experiment will provide increased insight into the incidence rate and size of extra-terrestrial matter at extreme altitudes. (Space Physics Laboratory and Optics Physics Laboratory)

NOTICE TO OUR READERS

Requests for further information should be directed to the individual or laboratory of origin.

Addresses are as follows:

AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
Attn: CRI
Laurence G. Hanscom Field, Bedford, Massachusetts

AERONAUTICAL RESEARCH LABORATORIES
Attn: ARB
Wright-Patterson Air Force Base, Ohio

AIR FORCE OFFICE OF SCIENTIFIC RESEARCH
Attn: SRIL
Tempo D Building
4th and Independence Avenue, S.W., Washington 25, D. C.

OFFICE OF RESEARCH ANALYSIS
Attn: RRR
Holloman AF Base, New Mexico

Detailed documentary reports may be obtained from:

OFFICE OF TECHNICAL SERVICES
U.S. Department of Commerce, Washington 25, D. C.

ARMED SERVICES TECHNICAL INFORMATION AGENCY*
Arlington Hall Station, Arlington 12, Virginia
*** Qualified requestors**

RESEARCH REVIEW is published by the Office of Information (RREI), Office of Aerospace Research, USAF, Washington 25, D. C. The frequency of this publication is determined solely on the basis of the availability of significant material to report. The objective is to make a positive contribution to the exchange of information about Air Force sponsored and conducted basic research activities. Individuals or groups associated with basic research may obtain copies by written request to the above address.

GPO 939177